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(09/2009)

An interference reduction technique by adaptive-array earth station antennas for sharing between the fixed-satellite service and fixed/mobile services

S Series

Fixed-satellite service

International Telecommunication Union

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REPORT ITU-R S.2150

An interference reduction technique by adaptive-array earth station antennas for sharing between the fixed-satellite service and fixed/mobile services

(2009)

Scope

This Report describes an interference reduction technique using adaptive-array earth station antennas for sharing between the FSS and fixed/mobile services. This technique may be used to improve FSS link performance when sharing the same frequency band with other services. The Report contains the theoretical analysis and field test results as well as observations to provide guidelines for the system design when employing the interference reduction technique.

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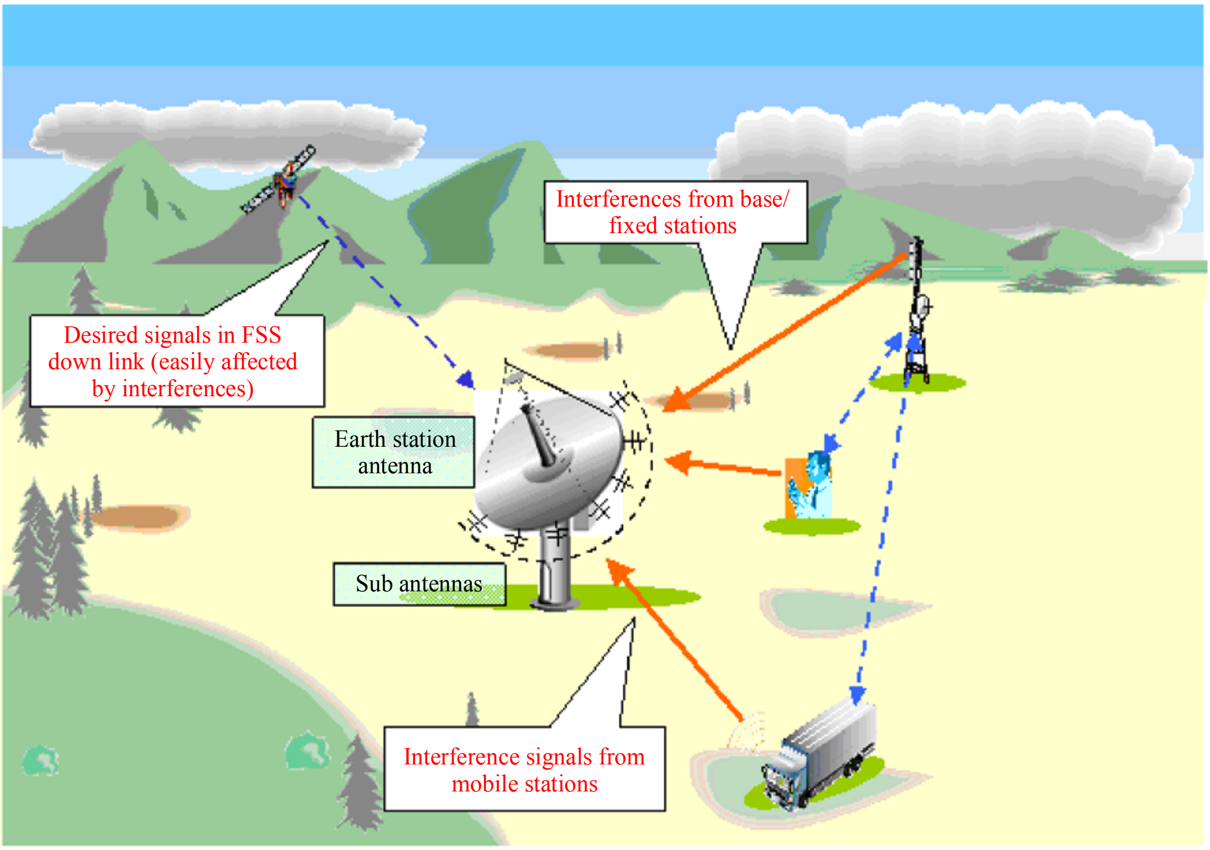
1 Introduction

As one of the possible measures to improve link performance of the fixed-satellite service (FSS) systems, an interference reduction technique by adaptive-array antenna would be considered.

In this technique, as shown in Fig. 1, interference signals from stations of fixed/mobile services (i.e. base/fixed stations or mobile stations) are reduced at a FSS earth station antenna by digitally processing signals received at a main earth station antenna (denoted as “main antenna” hereafter) and sub-antennas aligned around the main antenna. Each sub-antenna has the directivity in the horizontal plane and covers a part of the direction that interference signals arrive.

FIGURE 1

Overall concept for interference reduction



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In this Report, the overview of interference reduction technique using adaptive-array antennas is presented firstly. Next, the theoretical analysis and implementation of prototype interference reduction is discussed. Subsequently, test results of field trials conducted in a satellite teleport are presented. Finally, consideration of test results and system design guidelines are provided.

It should be noted that this Report addresses only the technical aspects of the presented interference reduction technique. As with any technology or interference reduction technique, there will be tradeoffs associated with balancing the complexity and cost of implementing the technique with the benefit derived from its implementation. Analysis of such tradeoffs is beyond the scope of this Report as such tradeoffs will be unique to every situation. The reader is advised that cost/benefit considerations are very important and should be carefully weighed when considering the possible implementation of such technologies.

2 Overview of interference reduction technique using adaptive-array antennas

Figure 2 depicts the principle of the interference reduction technique using adaptive-array antennas. A number of sub-antennas (N sub-antennas) are aligned around the main antenna. The number of interferers is assumed to be M in this case.

At the main antenna, the interfering signals ($J_{01}(t)$ to $J_{0M}(t)$: either from mobile stations or base/ fixed stations) are received in addition to the desired signal from a satellite $s(t)$. The signal received at the main antenna, $x_0(t)$, is expressed by:

$$x_0(t) = s(t) + J_{01}(t) + \cdots + J_{0M}(t) \tag{1}$$

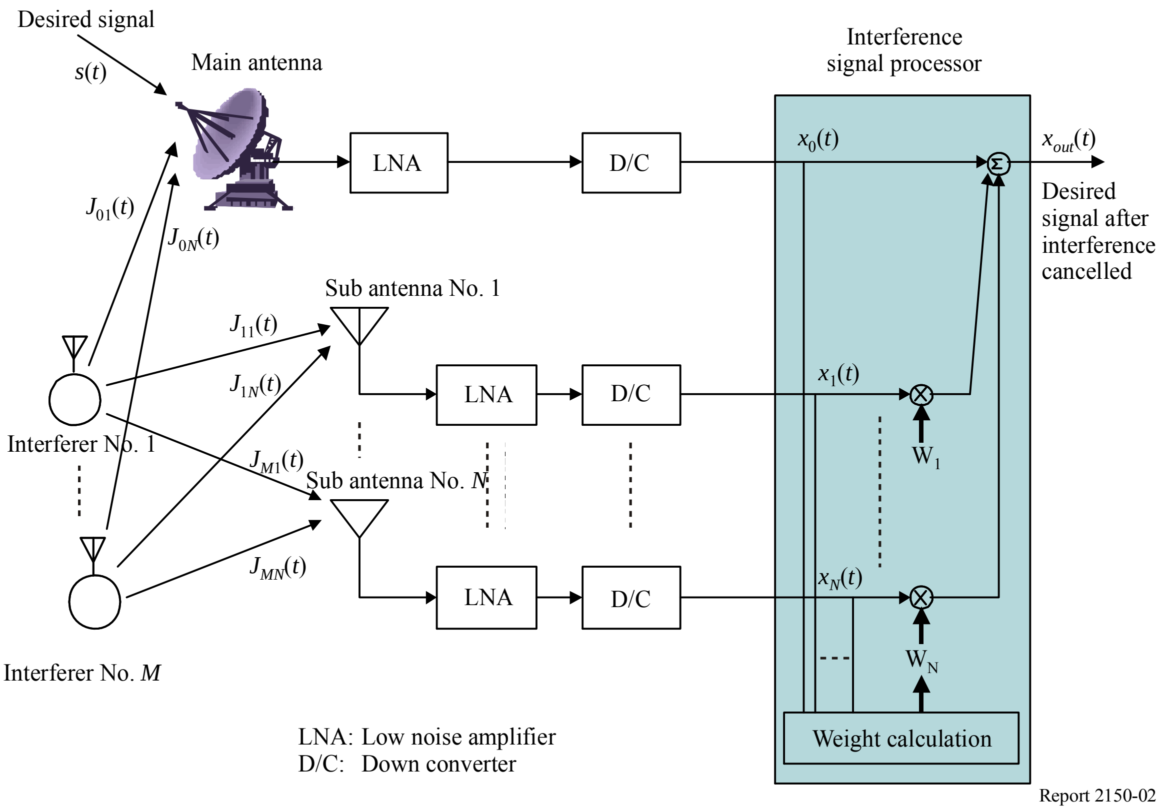
At the sub-antennas (No. 1 to No. N), only the interfering signals are received and no desired signal is received since the antenna gain of sub-antennas towards the satellite is too low to sense the very weak signal from the satellite. As a result, the signal received at the k-th sub-antenna $x_k(t)$ is expressed by:

$$x_k(t) = J_{k1}(t) + \cdots + J_{kM}(t) \tag{2}$$

Aggregated signals received at the main and sub-antennas (= $x_0(t) + x_1(t) + \ldots + x_N(t)$) are digitally processed by the "interference signal processor" (ISP) in Fig. 2.

FIGURE 2

Principle of the interference reduction technique



Consequently, the following signal is produced as a desired signal after interference reduction:

$$x_{out}(t) = x_0(t) + \sum_{k=1}^{N} w_k \cdot x_k(t) \tag{3}$$

where w_k is a weighting factor (or "weight"), that is adaptively computed by the interference signal processor, to multiply to the received signal at the k-th sub-antenna in order to minimize interference signals.

3 Theoretical analysis on the performance of interference reduction

Figure 3 shows a simple model to estimate the performance of interference reduction. By the principle of interference reduction technique, the system noise of the main antenna (i.e. the path for the desired signal) increases due to the additional noise incurred by the sub-antenna even though the operation of "correlation" (or calculation of weight) in Fig. 3 is ideal. The residual noise after the interference reduction (i.e. the increment noise as to the original system thermal noise without interferences), r, is expressed by:

$$r = \frac{\dfrac{I_1}{N_1}}{\dfrac{I_2}{N_2}} \tag{4}$$

where I_1, N_1 and S_1 represent the received levels of the interference signal, system thermal noise(excluding the interference) and desired signal at the main antenna and I_2 and N_2 represent those at the sub-antennas. The value r is regarded as a theoretical limit of the interference reduction technique in terms of incremental noise.

FIGURE 3

Estimation of interference reduction performance

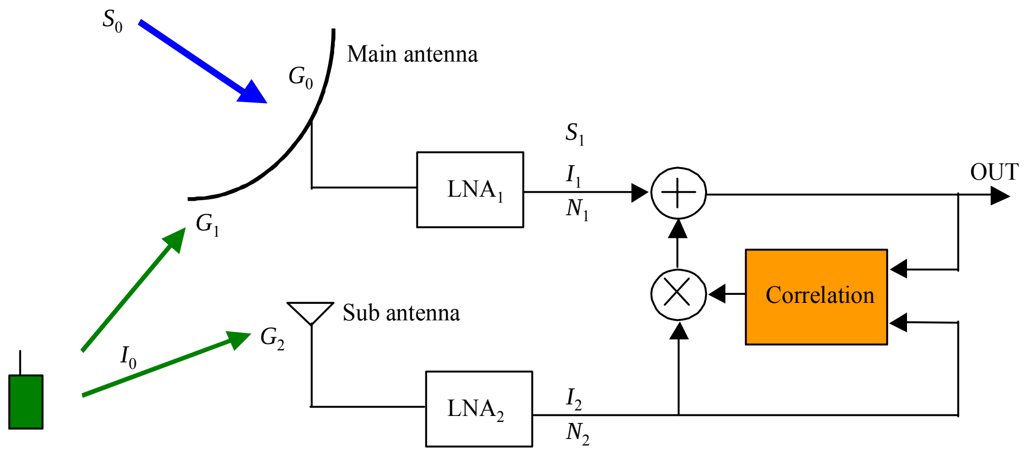


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Table 1 shows an example set of parameters. Assuming that the propagation loss from the interferer to the main antenna is equivalent to that to the sub-antenna, I_1/I_2 is proportional to the ratio of antenna gain between the main and sub-antenna in the direction of the interference arrival (i.e. G_1/G_2). N_1/N_2 is proportional to the ratio of system noise between the main and sub-antennas. For receiving the benefit of interference reduction, it is necessary to keep the value of G_1/G_2 as small as possible.

TABLE 1

Example parameters

Category	Item	Value	Note
Interfering signal	Frequency	3 900 MHz	Note 1
	Bandwidth	20 MHz	
	Transmit e.i.r.p. No. 1	46 dBm	For base stations
	Transmit e.i.r.p. No. 2	30 dBm	For mobile stations
Main antenna	Antenna gain	−10 dBi	Φ > 48º (Ref. Recommendation ITU-R S.465)
	System noise temperature	100 K	
Sub-antenna	Antenna gain	8 dBi	
	System noise temperature	400 K	

NOTE 1 – The purpose of 4 GHz band in Table 1 is to align the field trial described in § 5 of this Report and the applicability of the technique is not limited to particular frequency bands.

From the parameters shown in Table 1, the value of r is calculated as −12 dB, which corresponds to approximately 6% increase of the system noise floor of received FSS downlink. In this case, the G_1/G_2 is −18 dB. Note that further improvement could be expected since the antenna gain of the main antenna in the side-lobe region is typically better than −10 dBi in many cases. However, by the nature of interference reduction technique, it would be difficult to cancel the interference arriving from boresite direction of the main antenna.

Figure 4A/4B shows the relation between the distance to interferer and the I/N value and received level at the main antenna based on the parameters in Table 1. It is assumed that the interferer is either a mobile station or a base/ fixed station (single entry). Theoretically, the interference signal could be cancelled with the residual noise determined by equation (4) above left. The difference between the input I/N (before interface reduction) and the residual I/N (after interface reduction) is defined as the "reduction gain" as illustrated in Fig. 4A.

Naturally, the smaller the distance to interferer (or the larger received interference signal level), the larger the required reduction gain. For instance, it is seen from Fig. 4A that more than 40 dB reduction gain is required when the distance to interfering base station is within 2 000 m. The required reduction gain would have an influence on the design of the interference signal processor (e.g. the number of bits in computation to determine the dynamic range and so forth).

Furthermore, the maximum received level shown in Fig. 4B would be important in the system design to ensure the front-end LNA (Low noise amplifier) of the main antenna is not saturated. Typically, the maximum permissible level at the LNA input is around −65 dBm in aggregation. Operational scenarios (distance to interferers and transmit power of interferer) should be determined taking into account these elements.

FIGURE 4A

Relation between distance to interferer and *I*/*N* at the main antenna

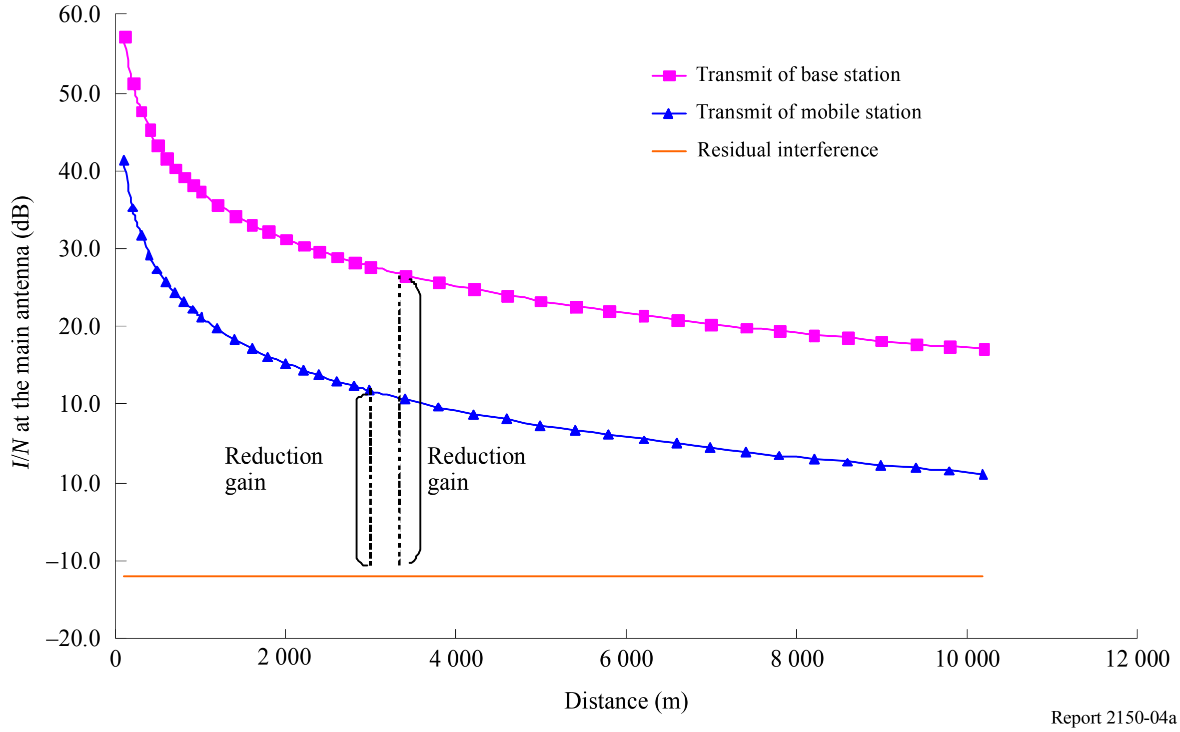
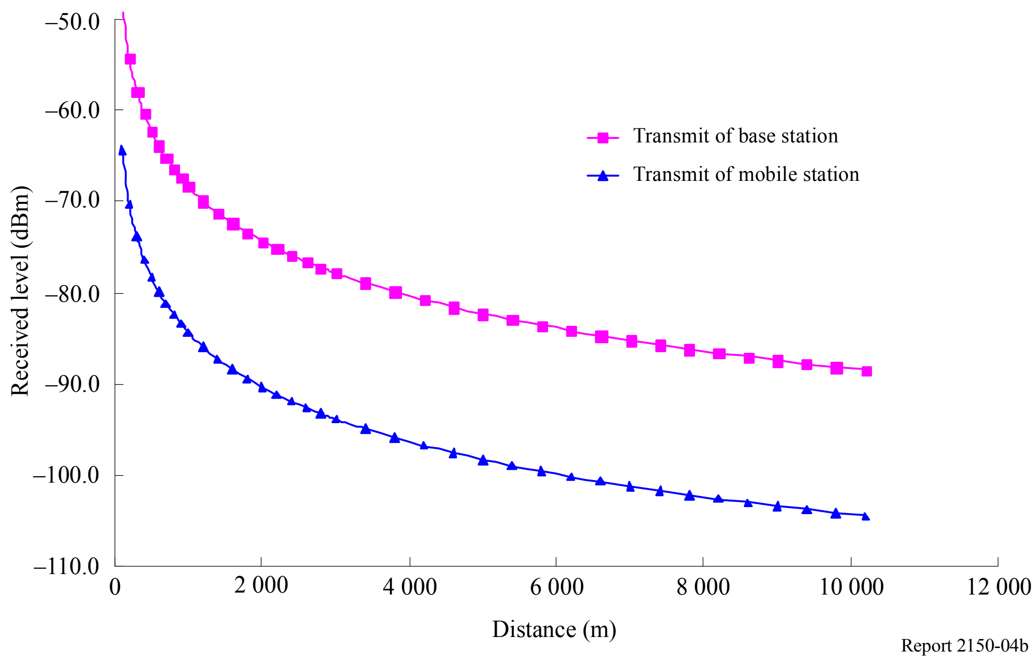


FIGURE 4B

Relation between distance to interferer and received level at the main antenna

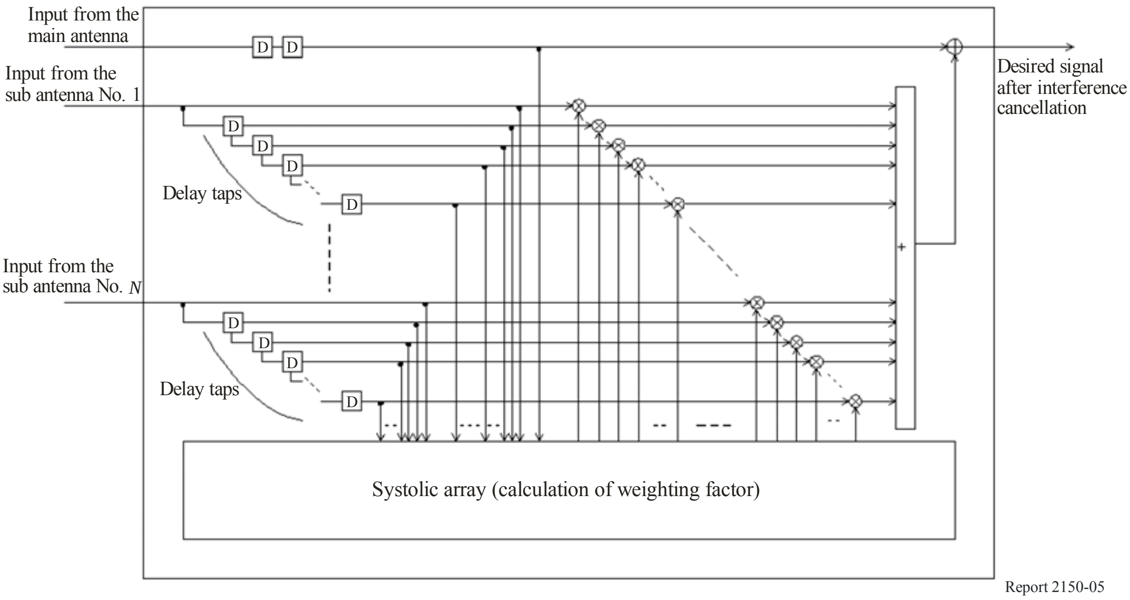


4 Implementation of prototype interference reduction system

In order to verify the performance of interference reduction technique, the prototype interference reduction system is developed. The prototype system has the basic configuration shown in Fig. 2. The general diagram of the "interference signal processor" part is shown in Fig. 5. The signals from the main antenna and sub-antennas (No. 1 to No. *N*) are fed into the processor for calculation of weight values by systolic array. Delay taps (shown as boxes "D" in Fig. 5) are useful to correct relative delays between the main and sub-antennas since the path length from the interferer to the main antenna differs from that to the sub-antennas in general. By nature, the performance of interference reduction would be degraded in presence of the above-mentioned relative delays. It should be noted that the computation amount by systolic array is proportional to the square of the number of input signals. In Fig. 5, it is approximately proportional to the square of $N^*(1 + N_d)$ where N_d represents the number of delay taps for each sub-antenna.

FIGURE 5

General diagram of interference signal processor



In implementing the prototype system, it is important to understand the nature of the desired and interfering signals as identified below:

– the received power of interfering signals can be much larger than that of the desired signal both at the main antenna and sub-antennas. At sub-antennas, the desired signal is not received or negligibly small;

– relative delays in the arrival time of interference signals between the main and sub-antennas may exist;

– due to motion of interferers and multipath fading effect, the received interference signals may vary quite rapidly;

– simultaneous interferences from multiple interferers may be present.

Taking into account the above, two types of platform are adopted for the prototype system to evaluate the trade-off of key design elements of interference signal processor as listed in Table 2.

TABLE 2

Platform of prototype interference reduction system

Item	Type-1	Type-2
Algorithm	DCMP/RLS[(1)]	DCMP/RLS[(1)]
Device for computation	CPU (DSP)/ Floating point computation	FPGA/ Fixed point computation
A/D converter's clock	120 MHz	120 MHz
Update cycle of weights	270 µs	8.33 ns
No. of sub-antennas	10	7
Delay taps	YES (6 delay taps for each sub-antenna)	NO (delay fixed)

(1) DCMP: Directional-constrained minimization of power, RLS: Recursive least square.

Type-1 systems employ the DSP (Digital signal processor) for computation. Since the floating-point computation is used in this type, the results of calculation (i.e. weight values) are more accurate (less computational error). On the other hand, Type-2 systems employ FPGA (Field programmable gate arrays) for the computation. Since the fixed-point computation is used, results of calculation are less accurate but faster computation is possible as compared to the DSP.

In addition, the number of input signals to the systolic array is 71 in Type-1 as ten sub-antennas with six delay taps each are accommodated while that in Type-2 is eight (only seven sub-antennas without delay taps). As a result, there is a large difference in an achieved update cycle of weights between two types as shown in Table 2. In summary, Type-1 is advantageous in the "accuracy" and Type-2 is advantageous in the "update cycle" (i.e. 270 µs vs. 8.33 ns).

5 Field trials

5.1 Overview of field trials

In the field trials, the performance of prototype interference reduction system is verified using actual earth station antennas and interferers. The trials are conducted in Ibaraki Satellite Communication Centre (ISCC). ISCC is located in a suburban area, about 150 km north east of Tokyo along Pacific coast (see Fig. 6). ISCC has a flat terrain with the lengths of about 1 km in the east-west direction and 500 m in the north-south direction as shown in Fig. 7. Earth station antennas are concentrated in the southwest part of the premise. Figure 8 shows the overview photos of ISCC and Fig. 9 shows the photos of interferers (vehicle-mounted and portable).

FIGURE 6

Location of ISCC

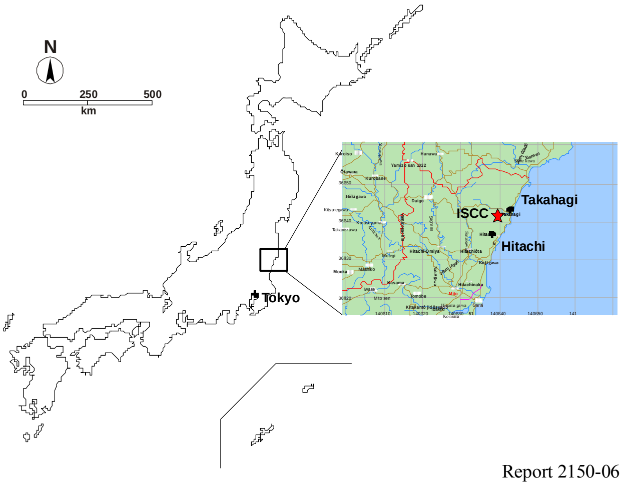


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FIGURE 7

Layout of ISCC

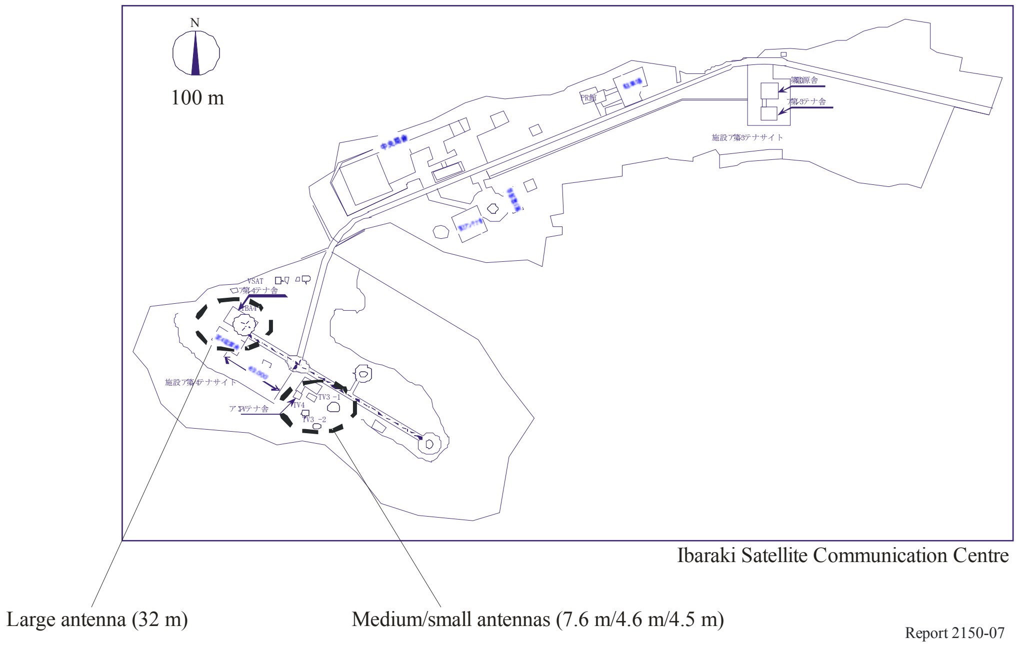

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FIGURE 8

Overview (photos) of ISCC

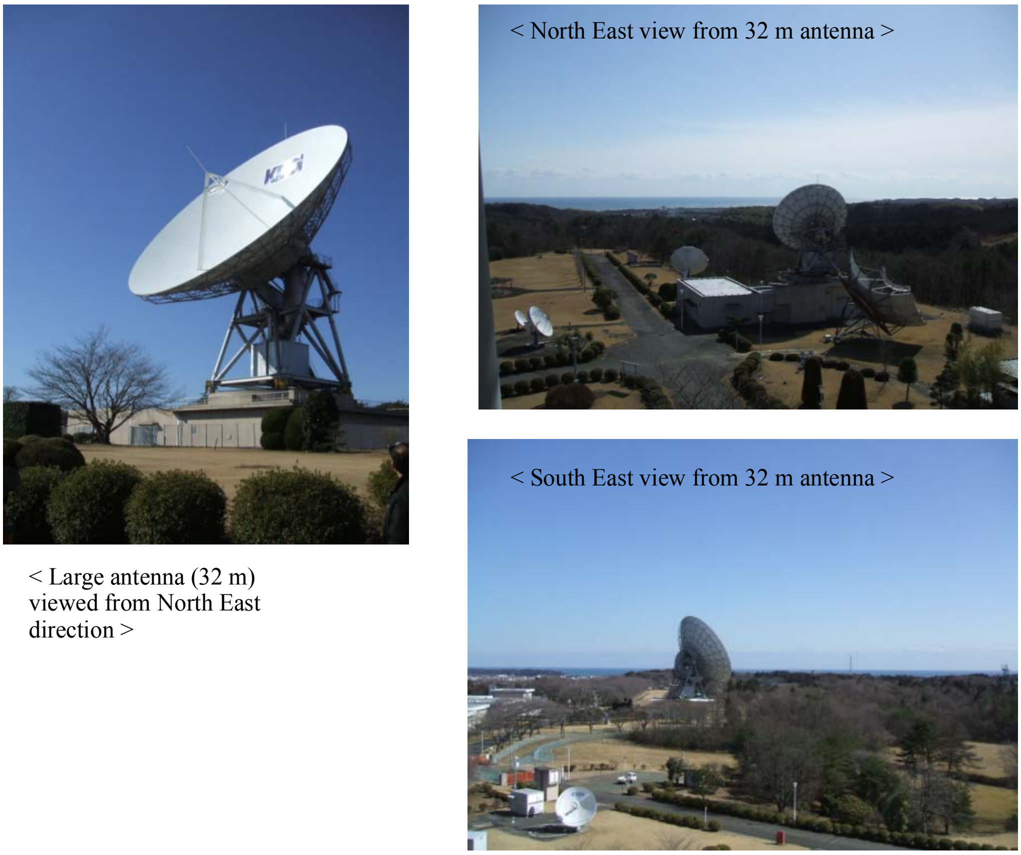

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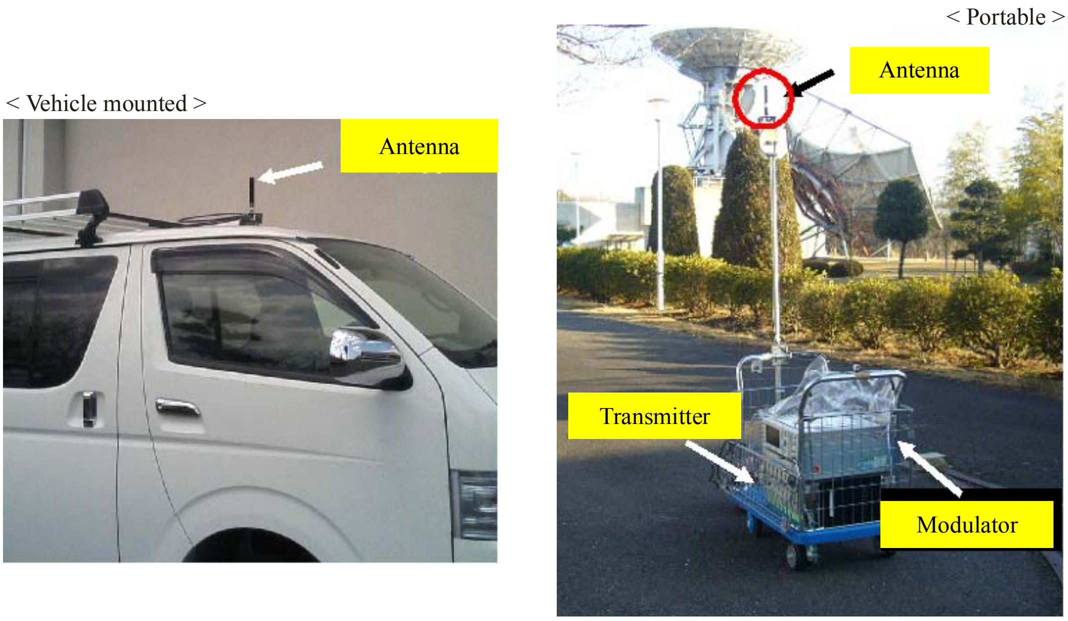
FIGURE 9

Photos of interferers



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In the field trials, delay profiles of interference signals are measured firstly as they would be important in understanding multipath effect on the interference reduction performance. Subsequently, the performance of interference reduction technique is verified using the prototype system.

5.2 Measurement of delay profiles

In this measurement, delay profiles of interference signals are measured. The test signal modulated by a periodical PN sequence is transmitted from a vehicle station that is located 100-200 m away from the main antennas (32 m/7.6 m). The signals received at the main and sub-antenna are recorded by a storage oscilloscope and the distribution of delays due to multipath propagation is obtained by calculating correlations between the transmitted and received signals. The parameter for the measurement is listed in Table 3.

TABLE 3

Parameters for delay profile measurement

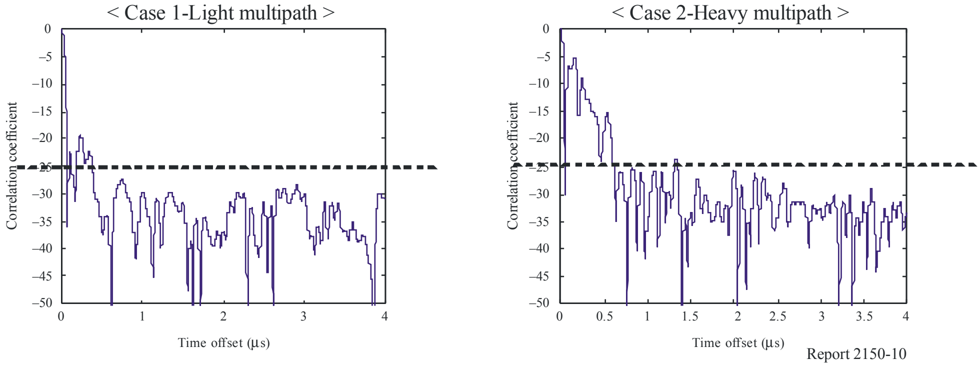
Category	Item	Value	Note
Test signal	Frequency	3 900 MHz	
	Symbol rate	12 Msymbol/s	
	Modulation	QPSK	Root-cosine filter (α = 100%)
	Information	PN7	M- Sequence
Received antennas	Main antenna	32 m/7.6 m	Received in side lobes (< –10 dBi)
	Sub-antenna	7 antennas	The antenna with the strongest reception is selected for each plot.
Received signal	Meas. period	80 μs	
	Sampling rate	1.25 GHz	T_s = 0.8 ns

An example of measured results received at 32 m antenna is shown in Fig. 10. In each plot, the abscissa (t) indicates the time offset of the delayed signal and the ordinate (p) indicates the correlation coefficient which corresponds to the levels of delayed signals. The direct signal is located at the origin of the plot (t, p) = (0,0). Note that signals less than –25 dB in each plot are not valid because of limitation floor of auto-correlation performance of the test signal.

In Fig. 10, only a few multipath signals are observed in case 1 while several strong multipath signals are observed in case 2. Note that the delayed signals are spread within 1 μs and most of strong delayed signals are within 500 ns in this measurement. Furthermore, another analysis using the eigenvalue calculation on the measured delay profiles reveal that as many as 4-5 multipath signals are observed in some cases (e.g. case 2) even with transmission by a single interferer.

FIGURE 10

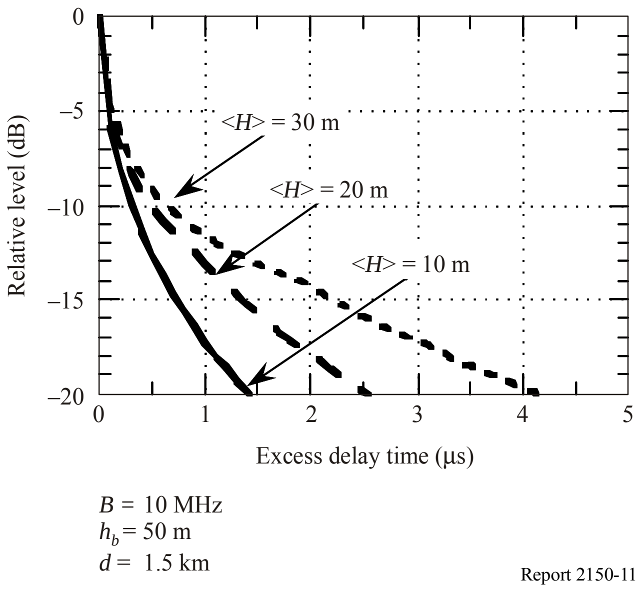
Measured result of delay profiles



Recommendation ITU-R P.1816 (approved in 2007) – The prediction of the time and the spatial profile for broadband land mobile services using UHF and SHF bands, illustrates examples of various propagations models and measured data. Figure 11 quoted from the Recommendation shows a typical delay profile (first path power) when the base station antenna height h_b, distance from the base station d and bandwidth *B* is 50 m, 1.5 km and 10 MHz respectively. The average building height <*H*> is 10 m, 20 m and 30 m treated as a variable. It can be seen that the case of <*H*> = 10 m (corresponding to suburban environment) in Fig. 11 shows a good match to the measured delay profiles in case 2 of Fig. 10.

FIGURE 11

Example of delay profiles (quoted from Recommendation ITU-R P.1816)



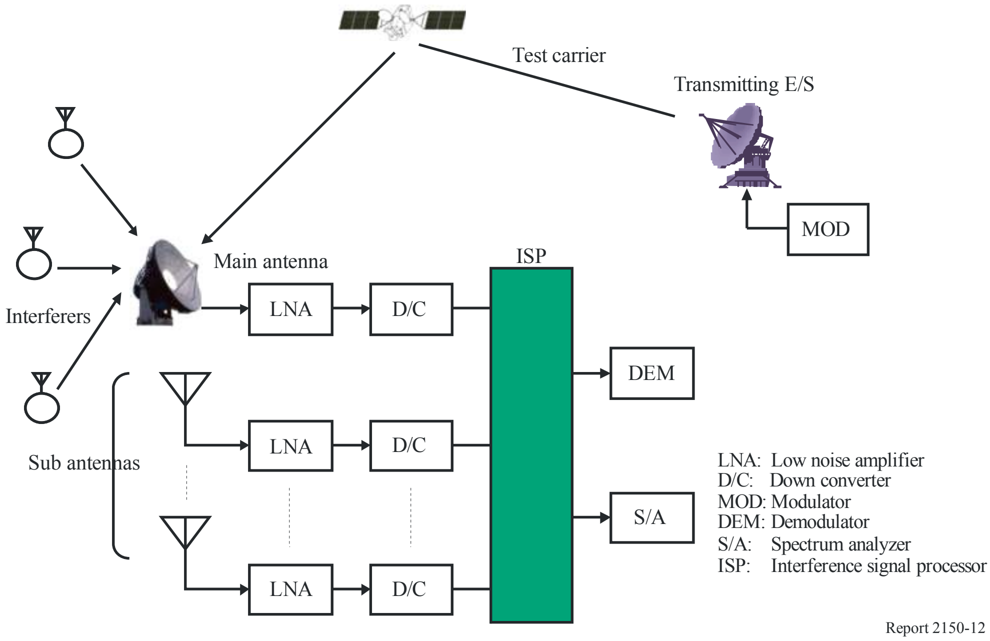
5.3 Performance of interference reduction technique

The performance of interference reduction technique is verified with the configuration depicted in Fig. 12. The test satellite carriers are transmitted from KDDI Yamaguchi earth station towards Intelsat-701 (180 E) and Asiasat-2 (100.5 E) with circular and linear polarization respectively and received by antennas in ISCC as listed in Table 4. Typical operational parameters for the transmission rate of 128 kbit/s – 2.048 Mbit/s (QPSK, 8-PSK and 8-QAM with 1/2, 2/3 and 3/4FEC) are used for the test satellite carriers. As for the interferers, vehicle mounted stations and portable stations are employed as shown in Fig. 9. Parameters for the interferers are listed in

Table 5. The maximum transmit power is 1 W and the bandwidth of interference signal is 20 MHz, 40 MHz or 120 MHz that are designated to be typical parameters of base/mobile stations for future mobile services. The prototype interference reduction system is equipped to the main earth station antenna.

FIGURE 12

Configuration of verification test



As for the choice of platform, it is decided to employ the Type-2 prototype system for the field trial since significant degradation in the performance is observed for the Type-1 system at the stage of preparatory tests. This is because many multipath signals produce more complex fast-varying fading than expected and frequency in updating of weight values in Type-1 system (i.e. 270 μs) is not sufficient in many cases.

TABLE 4

Characteristics of earth station antennas to be used for the field trial

Antenna No.	Diameter (m)	Satellite	Elevation angle	Polarization
1	32	Intelsat (180E)	31	Circular
2	7.6	Asiasat (100.5E)	30	Linear
3	4.5	Intelsat (180E)	31	Circular
4	4.6	Asiasat (100.5E)	30	Linear

TABLE 5

Characteristics of interferers

	Vehicle mounted/portable
Antenna type	Dipole
Antenna gain	0 dBi(1)
Frequency	3 900 MHz
TX power	1 W (0 dBW) maximum
Modulation Bandwidth	OFDM 20 MHz Multi-carrier (π/4DQPSK) 20 MHz/40 MHz/120 MHz

(1) No directivity is seen in the horizontal plane, but some directivity is seen in the vertical plane with the peak gain of about 3 dBi (at about 10º-15º of its elevation angle).

FIGURE 13

Photos of prototype interference reduction system

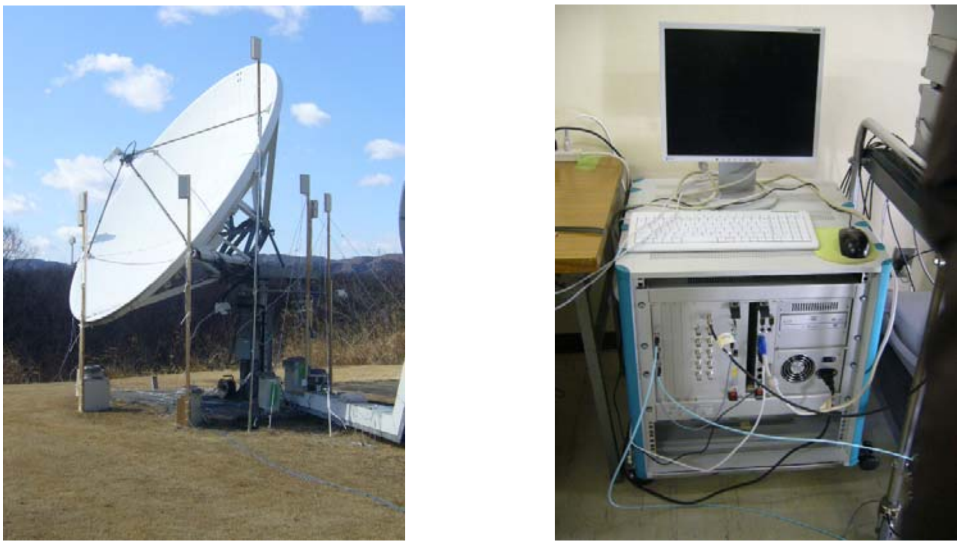


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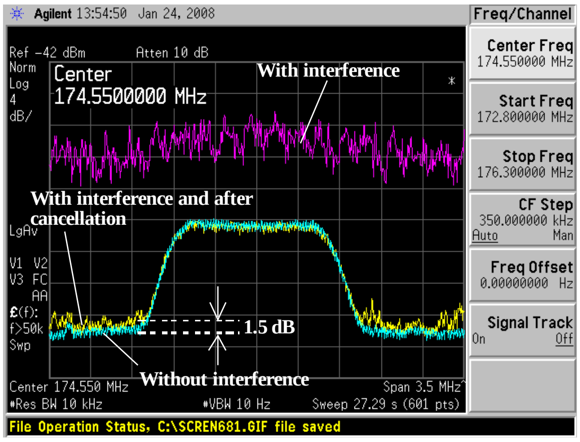
Figure 13 shows the photos of prototype interference reduction system. The left picture shows the main antenna (7.6 m) equipped with seven sub-antennas. The right picture shows the ISP part in Fig. 2 or Fig. 12.

Figure 14 shows screen trace of spectrum analyser to indicate the performance of interference reduction when interferers are stationary. In each plot, the received signal at the input of demodulator is captured showing “with interference before reduction” ($I + N$), “without interference” (N) and “with interference after reduction” ($I + N'$). N' means the residual interference after interference reduction.

FIGURE 14

Performance of interference reduction (stationary interferer)

Case 1



Received antenna: 32 m

Satellite: Intelsat-701 (180E)

Test carrier: QPSK 3/4FEC 2 Mbit/s

Interferer BW: 20 MHz

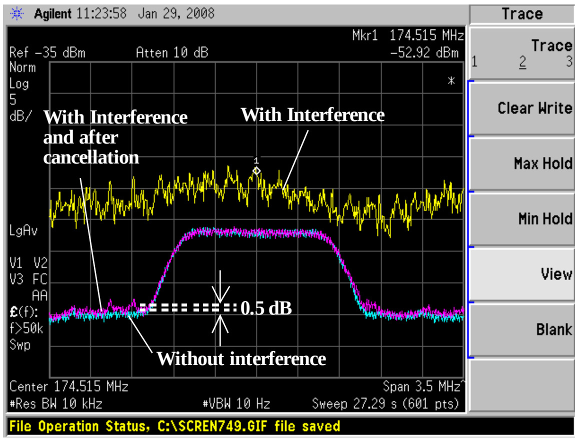
Interference power: 0 dBW

Distance: 70 m

Number of interferers: 1

Residual I/N: –4 dB (1.5 dB noise increase)

Case 2



Received antenna: 32 m

Satellite: Intelsat-701 (180E)

Test carrier: QPSK 3/4FEC 2 Mbit/s

Interferer BW: 20 MHz

Interference power: 0 dBW

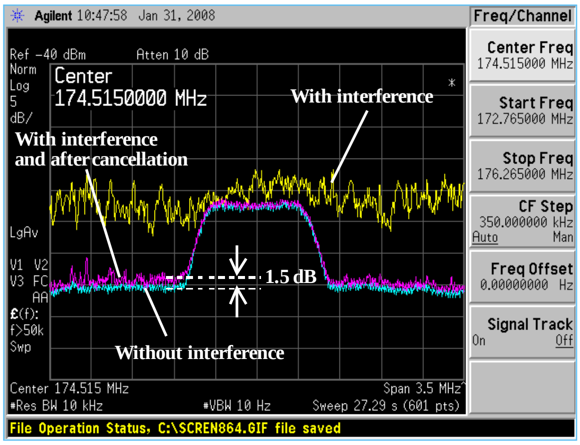
Distance: 100 m

Number of interferers: 1

Residual I/N: –9 dB (0.5 dB noise increase)

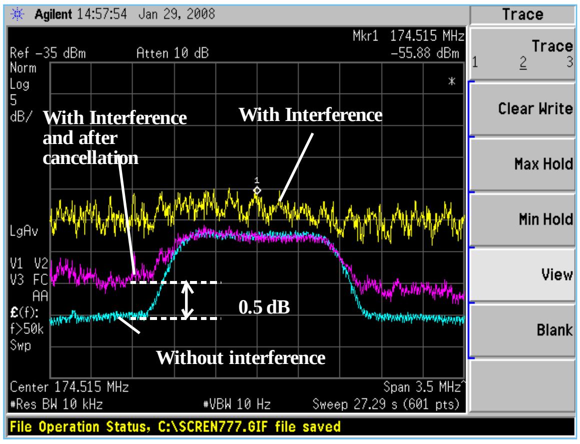
FIGURE 14 (*end*)

Case 3



Received antenna: 32 m
Satellite: Intelsat-701 (180E)
Test carrier: 8PSK 3/4FEC 2 Mbit/s
Interferer BW: 20 MHz
Interference power: 0 dBW
Distance: 100 m
Number of interferers: 1
Residual I/N: –4 dB (1.5 dB noise increase)

Case 4



Received antenna: 32 m
Satellite: Intelsat-701 (180E)
Test carrier: QPSK 3/4FEC 2 Mbit/s
Interferer BW: 20 MHz
Interference power: 0 dBW
Distance: 70-100 m
Number of interferers: 6
Residual I/N: 3.3 dB (5 dB noise increase)

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In case 1 to case 3, the number of interferers is one. In these cases, it is demonstrated that the interference is cancelled with the residual I/N only in the range of −9 to −4 dB left. On the other hand, in case 4 when a number of interferes (6 in this case) simultaneously transmit interference signals, a relatively large residual interference remains (i.e. I/N = 3.3 dB).

Table 6 shows the summary of test results in comparison with theoretical values. The received level and input I/Ns are much lower than theoretical values. This would be because the antenna gain of main antenna in the side-lobe region is lower than −10 dBi assumed in the theoretical analysis. Consequently, reduction gain is in the range of 22-29 dB in case 1 to case 3. The residual I/N is not as low as the theoretical value but below 0 dB (the residual noise is lower than the system noise floor) in case 1 to case 3. The cause of degradation in case 4 is discussed in § 6.

TABLE 6

Measurement results in comparison with theoretical values

Case	Theoretical values				Measured results			
	RX level	Input *I/N*	Residual *I/N*	Reduction gain	RX level	Input *I/N*	Residual *I/N*	Reduction gain
	(dBm)	(dB)	(dB)	(dB)	(dBm)	(dB)	(dB)	(dB)
1	–61.2	44.4	–12.0	56.4	–80.6	25	–4	29
2	–64.3	41.3	–12.0	53.3	–85.6	20	–9	29
3	–64.3	41.3	–12.0	53.3	–87.6	18	–4	22
4	N/a	N/a	N/a	N/a	–90.6	15	+3.3	11.7

Figure 15 shows the performance of interference reduction when interferers are moving. In this case, received interference power varies rapidly. The left figure shows the screen trace of spectrum analyser before interference reduction and the right picture shows the one after interference reduction. Unlike the stationary cases, it is not possible to cease transmission during measurement for comparison between "with interference" state and "without interference" state. Therefore Fig. 15 looks differently from Fig. 14. It shows about 30 dB reduction gain at maximum but some instantaneous residual interference remains.

FIGURE 15

Performance of interference reduction (moving interferer)

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6 Summary

From the test results shown in § 5, the following can be seen:

1 In the cases when the interferer is single and stationary, the reduction gain of about 30 dB is demonstrated in some cases with the residual *I/N* in the range of −4 to −9 dB left in contrast with the theoretical value (−12 dB).

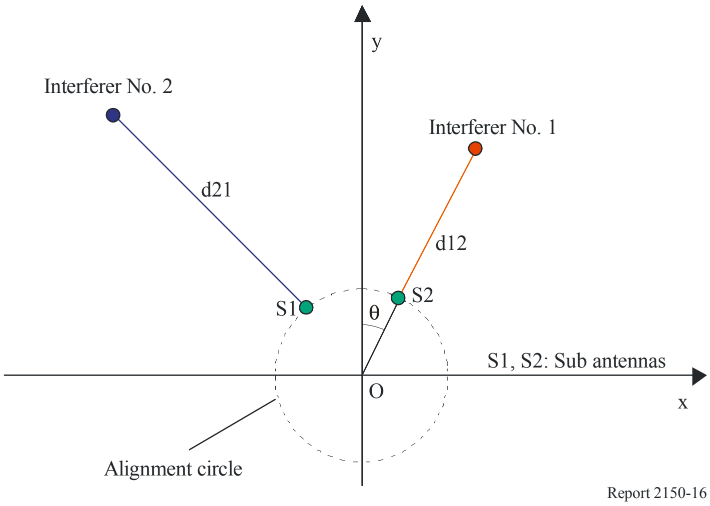
2 When a number of interference signals are simultaneously transmitted, the interference reduction performance is degraded (see case 4 in Fig. 14). The cause of degradation would be considered as follows. In the prototype system used for the field trials, only one weight is associated with each sub-antenna (i.e. no delay taps in Type-2 system). This configuration works well when interference signals are not received by adjacent sub-

antennas as shown in Fig. 16[1]. In this case, the weight corresponding to sub-antenna S1 and S2 can be determined independently on assumption that relative delays between the main antenna and sub-antennas are absorbed by adjusting delays (by manual adjustment in the case of Type-2 system). However, when interference signals are received by adjacent sub-antennas as shown in Fig. 17[1], the weight corresponding to sub-antennas S1 and S2 can no longer be uniquely determined because interferer No. 1 and No. 2 in Fig. 17 has different path delays with respect to the sub-antennas S1 and S2 respectively.

3 With regard to moving interferences, approximately 30 dB reduction gain is demonstrated (see Fig. 15) at maximum. However, some residual interference remains after the interference reduction. As an interferer moves, propagation paths of direct signal and multipath signals between the interferer and main/sub-antennas change. When the geometric relation between the interferer and main/sub-antennas produce severe multipath situation, they cannot be cancelled by the same reason as discussed in issue 2.

FIGURE 16

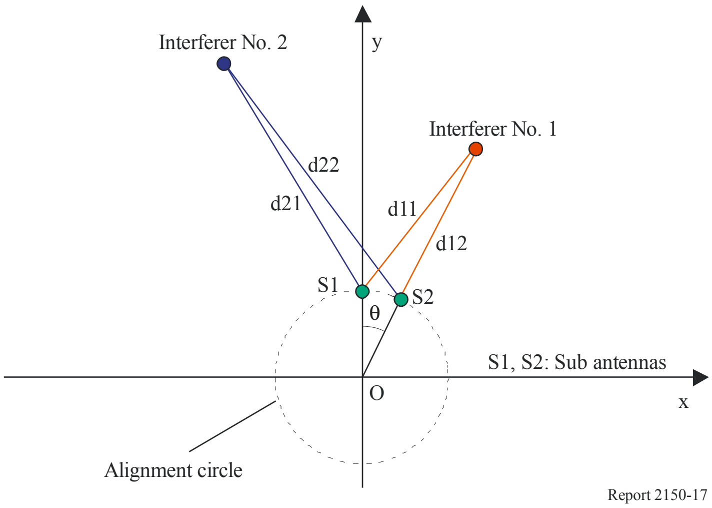
Scenario when the interference signal is not received by adjacent sub-antennas



[1] Although these figures show the case of two independent interference signals (i.e. No. 1 and No. 2), multipaths deriving from a single interferer (e.g. reflection at a building wall and other structures) have the same effect.

FIGURE 17

Scenario when the interference signal is received by adjacent sub-antennas



Considering the issues discussed above, the following need to be further studied towards the development of future operational systems:

a) in order to avoid "receiving coupling" problem between adjacent sub-antennas (see Figs 16 and 17), the delay taps shown in Fig. 5 are necessary. Frequent update of weights is also required as described in § 5.3. As a result, a platform with powerful computation ability is required, which could be achieved by the parallel FPGA configuration for instance. Furthermore, the following improvement would be also possible:

- to make the alignment circle of sub-antennas as small as possible to minimize the path difference (delay difference) even though the situation depicted in Fig. 17 occurs[2];
- to make the horizontal beamwidth of sub-antennas as narrow as possible to avoid for adjacent sub-antennas to receive "adjacent" interference signals (note that more sub-antennas are needed to cover a certain interference arriving directions);

b) in designing the interference reduction system, the following elements are carefully considered depending on the objective of system and feasible scalability of hardware:

- coverage of interference arrival;
- beamwidth of sub-antennas (resulting in the number of sub-antennas required);
- update frequency of weights (considering moving speed of interferers and multipath environment);
- sampling frequency of A/D converter (deriving from the bandwidth of interferers) as well as the interval of delay taps;

c) in this field trial, the knowledge of interference signals is not utilized. In operational systems, it would be important to actively utilize the knowledge to improve the performance (for instance, the reference to predetermined data symbols in the format of interference signals would be useful);

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2 If the delay difference is much smaller than the sampling time of A/D converter (8.3 ns equivalent to 2.5 m in this field trial), the effect would be negligible.

d) the operational scenario of interference reduction should be considered bearing in mind that, by nature, reduction of interferences from fixed/base stations is technically easier than that from mobile stations that are moving.

7 Conclusion

The interference reduction technique presented in this Report would be one option to improve FSS link performance when sharing downlink FSS spectrum with terrestrial radio communication services.

In this Report, the basic performance of the interference reduction technique using adaptive array antennas has been verified with field trials using a prototype system. In addition, key issues to be carefully considered when designing a system based on this type of interference reduction technique are identified.

7.1 Comparison with other interference reduction techniques

Since the technology presented in this Report is not sufficiently mature, relative benefits and disadvantages of employing these techniques should be carefully considered in comparison with other interference reduction techniques. Table 7 shows an example of comparison with a method to build a structure around the earth station to provide site shielding as described in Recommendation ITU-R SF.1486.

TABLE 7

Comparison of interference reduction techniques

Technology	Benefit	Disadvantage
Site shielding	No additional hardware/software to the FSS earth station equipment is needed	A large-scale structure would be needed in some cases to obtain the sufficient diffraction loss(1)
Interference reduction using adaptive array antenna	The flexible interference reduction would be realized regardless of the nature of interference signals (arriving direction, interference signal strength, etc.)	A relatively complex system is involved at the level of current technology. It might be alleviated with the further progress of digital processing technologies

(1) Practicability of building an artificial shield may depend upon available surrounding real estate.

7.2 Practicability of the interference reduction technique presented in this Report

In general, the benefit of the interference reduction technique using adaptive array antenna is greatest when used with relatively large earth station antennas where a large effect of improvement is expected (e.g. the large number of circuits carried by the antenna) at the level of current technology. To be implemented, this technique will requires some physical space around the FSS earth station antenna to install sub-antennas. It is also noted that the 4 GHz band is not shared on a co-primary basis with the mobile service in all regions and thus these interference reduction techniques with respect to the mobile service may not be applicable in all locations.

The following are some notes on practicability of the interference reduction technique presented in this Report:

Optimization in sub-antenna installation

The basic number of sub-antennas is determined by arriving direction of interference signals, allowance of path difference and the radius of alignment circle (see Figs 16 and 17). Table 8 shows an example set of a sub-antenna installation assuming that 20 ns of path difference is allowed.

TABLE 8

Example of sub-antenna installation

Alignment circle (m)	Separation angle (degrees)	Arrival direction (degrees)	No. of sub-antenna(1)
10	30	360	12
10	30	180	6
1	90	360	4

(1) Note that sub-antennas should be positioned with beam overlapping when the multipath from a particular direction is particularly heavy.

Additional cost of installing the interference reduction technique

The interference reduction system consists of sub-antennas and an ISP as depicted in Fig. 2. Since the ISP is an FPGA-based digital circuit and the hardware cost is not significant, the main cost driver would be sub-antennas part including a number of low noise amplifiers and down converters.

Assuming the configuration has seven to eight sub-antennas, typical incremental hardware costs are shown in Table 9 as proportions to the total earth station antenna costs of 18 m, 11 m and 4.5 m antennas, respectively.

TABLE 9

Typical incremental hardware cost indication

Antenna diameter (m)	Incremental cost (2009) (%)
18	3
11	5
4.5	20

Collaboration between FSS systems and interfering systems

In order to maximize the effect of interference reduction, exchanging information between FSS system and interfering system operators will aid in achieving an optimum in interference reduction.